A New Classification Method Based on Cloude-Pottier Eigenvalue/eigenvector Decomposition

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***Abstract*—In this paper, a new polarimetric scattering parameter, the averaged intensity (*I*), is introduced to present the backscatter intensity of fully polarimetric SAR data. According to the particular analysis on the properties of *I*, *α* angle and entropy *H*, the mapping rule of *I-α-H* feature space onto the Intensity-Hue-Saturation (*I-H-S*) color space is proposed. We use the IHS transform instead of segmentation algorithm to finish the classification. The important advantages of this method are that the information contained in the *I-α-H* feature space is preserved without any loss in the resulting image, and the execution time is saved since IHS transform is faster than most complicated segmentations. The result shows that *I* has the additional information which is not contained in *α* and *H*, and the classification result is more readable than that of *H*/*α*/*A*.**

Keywords-averaged intensity (I); Intensity-Alpha-Entropy (I-α-H) feature space; Intensity-Hue-Saturation (I-H-S) color space; Intensity Hue Saturation (HIS) transform; Cloude-Pottier decomposition; unsupervised classification; polarimetric SAR

I. INTRODUCTION

Many methods are developed for classification of fully polarimetric SAR data, one of which, the Cloude-Pottier decomposition [1], has gained great popularity. The most important advantages of this decomposition are that it's capable of covering the whole range of scattering mechanism and automatically basis invariant. This decomposition is based on the eigenvalue/eigenvector calculation of the coherency matrix of fully polarimetric SAR data. From this decomposition, a set of feature parameters can be extracted, which contain the polarimetric scattering information within the SAR data. A feature space can be formed using this parameter set. Then the specific processing technique, such as segmentation, can be applied to the feature space to obtain the classification result.

There are two sticking points need to be considered. One is the way to choose the feature space, the other is the process applied to the space. In general, different parameter presents different information. There are three most commonly used feature parameters *H*/*α*/*A*, which present entropy, scattering angle and anisotropy respectively. In recent years, much research has been done on the use of different segmentation approaches to improve the classification performance. Despite the great improvement of segmentation algorithm, the resulting image doesn't provide a sufficient resolution compared with the single channel amplitude images. There may be two reasons. One is *H*/*α*/*A* only contain the information of the three scattering mechanisms with relative values and ignore the information of backscatter intensities with absolute values, the other is the segmentation processing loses too much information to maintain the performance. Thus it would help to use new parameter to present the intensity information and to propose a more desirable processing technique to replace the segmentation. This is precisely the aim of this paper.

Some previous research has already done for this. For examples, Hellmann chooses the first eigenvalue (λ_1) [2], and Kimura the total power (*SPAN*) [3] to present the backscatter intensity. From the experimental results, it shows that the image of λ_1 is too noisy and the image of *SPAN* doesn't have the same geometry as those of *H*/*α*. Besides, since they all use hyper-box to perform the segmentation, the results are not apparently improved compared with the methods using advanced segmentation algorithms. In this paper, we use the averaged intensity *I* combined with the Intensity Hue Saturation (IHS) transform [4] to get a very good classification result.

In the section II, the Cloude-Pottier decomposition is outlined as the basic theorem of this paper. Then the averaged intensity *I* is extracted and its characteristics are described in detail. In the section IV and section V, we form the *I-α-H* feature space and illustrate its similarity with the *I-H-S* color space. Then the mapping rule between the *I-α-H* feature space and the *I-H-S* color space is interpreted. In the section VI, the whole procedure of this classification is analyzed. Finally, the conclusion is given with some discussion on the characteristics of this classification method.

II. CLOUDE-POTTIER DECOMPOSITION

Due to the reciprocity theorem [1], the scattering matrix [*S*] is given by

$$S = \begin{bmatrix} S_{vv} & S_x \\ S_x & S_{hh} \end{bmatrix} \tag{1}$$

, where the first index denotes the received polarization and the second denotes the transmitted polarization. [*S*] can be expressed as a vector using Pauli basis

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$$k = \frac{1}{\sqrt{2}}[S_{vv} + S_{hh}, S_{vv} - S_{hh}, 2S_x]^T \quad (2)$$

Then the coherency matrix [T] has the form

$$T = \left\langle kk^{*T} \right\rangle \quad (3)$$

, where $\langle\ \rangle$ denotes ensemble averaging. Since [T] is a hermitian, positive, semi-definite matrix, it can always be applied an eigenvalue analysis. Thus [T] can be decomposed into three parts

$$T = \lambda_1 e_1 \cdot e_1^{*T} + \lambda_2 e_2 \cdot e_2^{*T} + \lambda_3 e_3 \cdot e_3^{*T} \quad (4)$$

, where λ_i are the real eigenvalues of [T] which follow $\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq 0$, and e_i are the corresponding orthonormal eigenvectors written as

$$e_i = [\cos\alpha_i, \sin\alpha_i \cos\beta_i e^{i\delta_i}, \sin\alpha_i \sin\beta_i e^{i\gamma_i}]^T. \quad (5)$$

Each part in (4) presents a scattering contribution, and the amount of the contribution is given by λ_i while the type of scattering is given by e_i. The probability of each scattering mechanism is expressed as

$$p_i = \frac{\lambda_i}{\sum \lambda}. \quad (6)$$

The three most widely used parameters are described in the following.

- Entropy $$H = -\sum_{i=1}^{3} p_i \log_3 p_i \quad (7)$$
- α angle $$\alpha = p_1\alpha_1 + p_2\alpha_2 + p_3\alpha_3 \quad (8)$$
- Anisotropy $$A = \frac{p_2 - p_3}{p_2 + p_3} \quad (9)$$

The physical interpretations and other details of these three parameters can be found in [1]. From the classification results, it can be seen that neither $H/\alpha/A$ nor H/α provides a satisfactory interclass resolution.

III. THE AVERAGED INTENSITY

To avoid this, firstly, a new parameter with better performance is needed. For the approach described in this paper, we introduce the averaged intensity I to reform the commonly used H-α-A feature space. This parameter is based on the Cloude-Pottier decomposition and given by

$$I = \lambda_1 p_1 + \lambda_2 p_2 + \lambda_3 p_3 \quad (10)$$

, where λ_i are the intensities of the three scattering mechanisms, and p_i are the corresponding weighting coefficients which present the probabilities. In order to make the gray image I more readable, the logarithm is taken by default.

The parameter I contains the intensity and probability information of the whole three scattering mechanisms in (4). Moreover, (10) can be seen as a fusion method of the three channels fully polarimetric SAR data.

The major characteristics of I are described in the following.

- Polarimetric roll invariance
- Speckle reduction inherently
- Fusion of the intensity information of the three scattering mechanisms corresponding to the three parts in (4)
- Containing the probability information of the three scattering mechanisms
- Having the same geometric characteristics as $H/\alpha/A$
- Having better interclass resolution than $H/\alpha/A$
- Independence on H/α in physical conception
- Dependence on the de-speckling algorithm used to calculate the coherency matrix [T]
- No additional computation burden

This analysis indicates that the averaged intensity I shall be useful to extract information from polarimetric SAR data. The experimental result shows that I is particularly fit for maintaining the whole three channels' intensity, it has additional information which is not contained in α and H, and it shows a good speckle reduction performance with sufficient resolution (it relates to the de-speckling algorithm).

IV. I-α-H FEATURE SPACE

Based on the description in section III, we extend the H-α feature space using the averaged intensity I (Fig. 1). Choosing $I/\alpha/H$ to form the feature space is due to the special properties of $I/\alpha/H$ as shown in the section V. Besides, another reason is that in practice, α and H are seen to be more valuable than A to distinguish different scattering mechanisms.

In Fig. 1, the 3D box presents the I-α-H feature space. The base of the box is the well known 2D H-α plane, which presents the important properties of the three scattering mechanisms in (4). The vertical axis is the averaged intensity I. To simplify the presentation, the values of I are normalized to the interval 0~1.

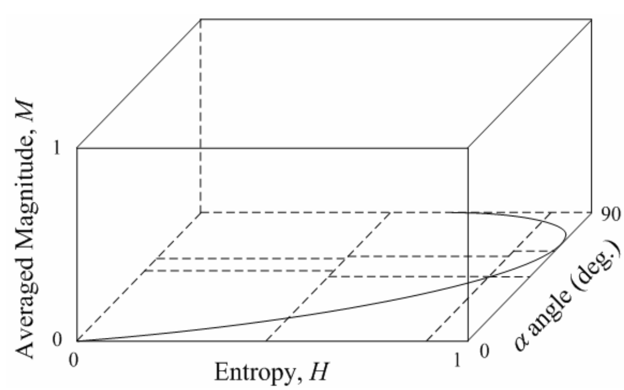

Figure 1. I-α-H feature space

In the next sections, we shall discuss the relationship between the *I-α-H* feature space and the Intensity Hue Saturation (*I-H-S*) color space. To avoid confusion, we shall use the low case $_f$ to present the *I-α-H* feature space, and $_c$ to *I-H-S* color space.

V. MAPPING OF *I-α-H* FEATURE SPACE ONTO *I-H-S* COLOR SPACE

We find out that according to physical conceptions, the *I-α-H* feature space is internally identical with the *I-H-S* color space (Tab. 1). A short view of *I-H-S* color space is given in APPENDIX A. More information can be found in [4]. Here we focus on the physical relationship between the *I-α-H* feature space and the *I-H-S* color space.

From Tab. 1, it is obvious that I_f, α_f, H_f are associated with I_c, H_c, S_c respectively. Hence, it is reasonable to establish the rule of mapping between the *I-α-H* feature space and the *I-H-S* color space. According to the dimension, there are 3 transformation functions needed.

A. $I_f \to I_c$

In scattering theory, I_f presents the backscatter intensity within each pixel. In computer graphics, I_c is the intensity of color of each pixel. As I_f varies from 0 to 1 (the value is normalized, see Sec. IV), the backscatter intensity increases. Additionally, as I_c varies from 0 to 1, the brightness increases. Thus the transformation between I_f and I_c is given by

$$I_c = I_f . \tag{11}$$

B. $\alpha_f \to H_c$

The relationship between α_f and H_c is obvious because they all present some kinds of “type”. α_f presents the type of the scattering mechanism. H_c presents the type of a color of the spectrum, such as red, green, yellow, etc.

Commonly, we prefer to set blue to water areas (odd bounce) and red to buildings (even bounce) in the result image. Therefore, the strategy used in this paper is that as α_f varies from 0 to 90°, the resulting color varies from blue, through cyan, green, yellow, to red (Fig. 2). This is a little different from the definition of H_c (APPENDIX A). We need to adjust the range of the output variable H_c, so the transformation function comes to be

$$H_c = \frac{2}{3}\left(1 - \frac{\alpha_f}{90}\right) \tag{12}$$

, where the unit of α_f is deg. It should be noted that (12) is not unchangeable, it can be modified according to our needs.

TABLE I. *I-α-H* FEATURE SPACE AND *I-H-S* COLOR SPACE

***I-α-H* Feature Space**		***I-H-S* Color Space**	
Component	***Description***	***Component***	***Description***
I_f	backscatter intensity	I_c	intensity of color
α_f	scattering type	H_c	type of color
H_f	degree of randomness	S_c	degree of purity

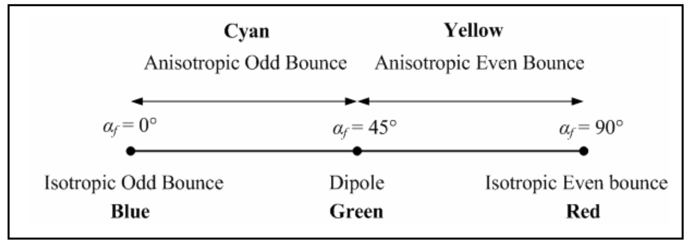

Figure 2. Interpretation of α_f

C. $H_f \to S_c$

Tab. 1 shows that H_f and S_c all present some kinds of degree. Note that when H_f = 0, the pixel contains only one (pure) scattering mechanism, and when H_f = 1, the pixel contains three equal (mixed) scattering components. That is to say, 0 presents the pure state, 1 the totally impure state. This description is just opposite to that of S_c (APPENDIX A), so the relationship between H_f and S_c is given by

$$S_c = 1 - H_f . \tag{13}$$

Using (11)-(13), we can easily map the *I-α-H* feature space onto the *I-H-S* color space. Next, the IHS transform (APPENDIX B) can be applied to convert the *I-H-S* color space to the *R-G-B* color space, so the final result of this classification is obtained.

VI. CLASSIFICATION

On the whole, the classification method given in this paper consists of three steps (Fig. 3).

- Calculation of $I_f/\alpha_f/H_f$ using (7), (8), and (10),
- Conversion from $I_f/\alpha_f/H_f$ to $I_c/H_c/S_c$ using (11)-(13),
- Using IHS transform to obtain the RGB resulting image.

Since α_f covers the whole range of scattering mechanism, this method is not like the usual classification methods which separate the data into a limited number of classes (each class presents one specific scattering mechanism), but some general principles still can be given, which are shown in the following according to the mapping rule used in this paper.

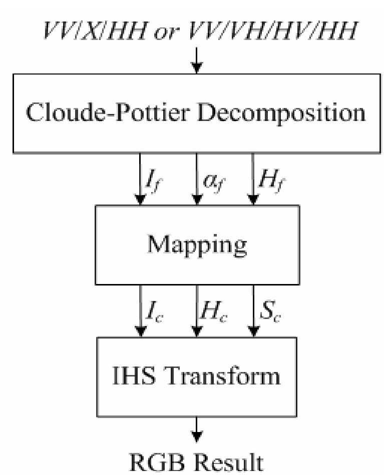

Figure 3. The proposed method for polarimetric SAR classsification

- Pixels with low I_f, low α_f and low H_f present smooth areas, such as water, the color of which shown in the final image is dark blue.
- Pixels with high I_f, high α_f and low H_f present buildings and man made structures, the color of which is bright red.
- Pixels with high H_f present forest. Since high H_f leads to low S_c (APPENDIX A), the color in the final image is gray.

This method has at least five advantages.

- It maintains the whole advantages of Cloude-Pottier Decomposition, such as covering the whole range of scattering mechanism and roll invariance.
- It includes the intensity information without additional computation burden.
- It doesn't have any information loss during the process of the transformation from the $I/\alpha/H$ feature space into the classification result.
- It is fast since no algorithm is needed to perform the segmentation.
- It is unsupervised.

The experimental results are in accord with this analysis. It shows that this $I/\alpha/H$ classification provides a much better performance than the common methods, especially for resolution. Moreover, since the IHS transform is faster than most currently used segmentation algorithms, it saves execution time.

It is important to note that the information contained in $I/\alpha/H$ is preserved without any loss in the resulting image. That is to say, the losses are only produced during the Cloude-Pottier decomposition. We find out that the speckle reduction algorithm is a really crucial point to optimize the performance. During our experiment, Lee filter [5] is chosen to calculate the coherency matrix [T], and the result shows it is good enough to satisfy our most application needs.

VII. CONCLUSION

A new polarimetric scattering parameter, the averaged intensity (I), has been proposed to present the backscatter intensity of fully polarimetric SAR data, and a new classification method has been developed in succession based on the Cloude-Pottier decomposition and the IHS transform theorem. This method has no information loss during the process of conversion from the feature space to the resulting image, and it is fast since no complex segmentation algorithm is needed. Besides, it is promising to use this method for further visual classification purpose.

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APPENDIX

A. I-H-S Color Space

Usually, color is described by assigning values to red, green and blue components, as given by (R, G, B). Here (R, G, B) formed a color space. There are other color spaces e.g. the *I-H-S* color space (which is also called *H-S-I* or *H-S-V* color space). The *I-H-S* color space is defined as the way humans think about colour. I, H, S are intensity, hue, saturation respectively. The definitions of I, H, S used in this paper are given in the following. More information can be found in [4].

1) Intensity (I) refers to the intensity or brightness of the light with a range of 0~1. When the light is at its fullest intensity, the color becomes bright, at its least intensity, the color becomes dim.

2) Hue (H) corresponds to the wavelength of light contributing to a color with a range of 0~1. As the hue varies from 0 to 1, the color varies from red, through yellow, green, cyan, blue and magenta, back to red.

3) Saturation (S) is the degree of purity of a color, which presents the amount of white light mixed in the color. The range of it is 0~1. When the saturation is 0, the color is only shades of gray. When the saturation is 1, the color contains no white light (pure color).

B. IHS Transform

The Intensity Hue Saturation (IHS) transform is used to convert from RGB color presentation to IHS color presentation, and vice versa. In geological applications, the IHS transform is demonstrated as a method to combine co-registered images from different sources. Details of the way to perform IHS transform are given in [4].

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